

## **2017 Astrophysics Division input for Government Performance and Results Act (GPRA) “Modernization Act (GPRAMA) review by Astrophysics Advisory Committee**

### **ASTROPHYSICS**

Over the past year, NASA’s Astrophysics Division has successfully continued its goal of addressing its primary strategic objective: “Discover how the Universe works, explore how it began and evolved, and search for life on planets around other stars.”

Combined with the support of many ground-based observatories, and relying on the dedication and hard work of thousands of astronomers, over the past year NASA Astrophysics missions have continued to make incredible progress in answering these questions. The Astrophysics Advisory Committee (APAC) unanimously judged the progress towards all three primary performance goals to be **GREEN**:

**Multiyear Performance Goal 1.6.2:** *Demonstrate progress in probing the origin and destiny of the Universe, including the nature of black holes, dark energy, dark matter, and gravity.*

**Multiyear Performance Goal: 1.6.3:** *Demonstrate progress in exploring the origin and evolution of the galaxies, stars, and planets that make up the Universe.*

**Multiyear Performance Goal: 1.6.4:** *Demonstrate progress in discovering and studying planets around other stars and exploring whether they could harbor life.*

While not strictly the purview of this report, the APAC wanted to note the tremendous success of the LISA Pathfinder mission, and looks forward to the future science that the success of this technology demonstration mission will facilitate.

We list a subset of the some of major Astrophysics Division milestones achieved using NASA facilities below.

Major Astrophysics milestones of the last year include:

- NuSTAR Finds New Clues to 'Chameleon Supernova'
- Astronomers Pursue Renegade Supermassive Black Hole
- Astronomers Discover Powerful Cosmic Double Whammy
- Collapsing Star Gives Birth to Black Hole
- Hubble Dates Black Hole’s Last Big Meal
- Observatories Combine to Crack Open the Crab Nebula
- Hubble Uncovers a Galaxy Pair Coming in from the Wilderness
- “Kitchen Smoke” Molecules in Nebula Offer Clues to the Building Blocks of Life
- NASA Telescope Reveals Largest Batch of Earth-Size, Habitable-Zone Planets Around Single Star
- NASA Releases Kepler Survey Catalog with Hundreds of New Planet Candidates
- Small Planets Come in Two Sizes

- NASA Study Finds Unexpectedly Primitive Atmosphere Around ‘Warm Neptune’

**Strategic Objective 1.6:** Discover how the Universe works, explore how it began and evolved, and search for life on planets around other stars.

**Multiyear Performance Goal 1.6.2:** *Demonstrate progress in probing the origin and destiny of the Universe, including the nature of black holes, dark energy, dark matter, and gravity.*

**Annual Performance Indicator: FY 2017 AS-17-1:** *Demonstrate planned progress in probing the origin and destiny of the Universe, including the nature of black holes, dark energy, dark matter, and gravity.*

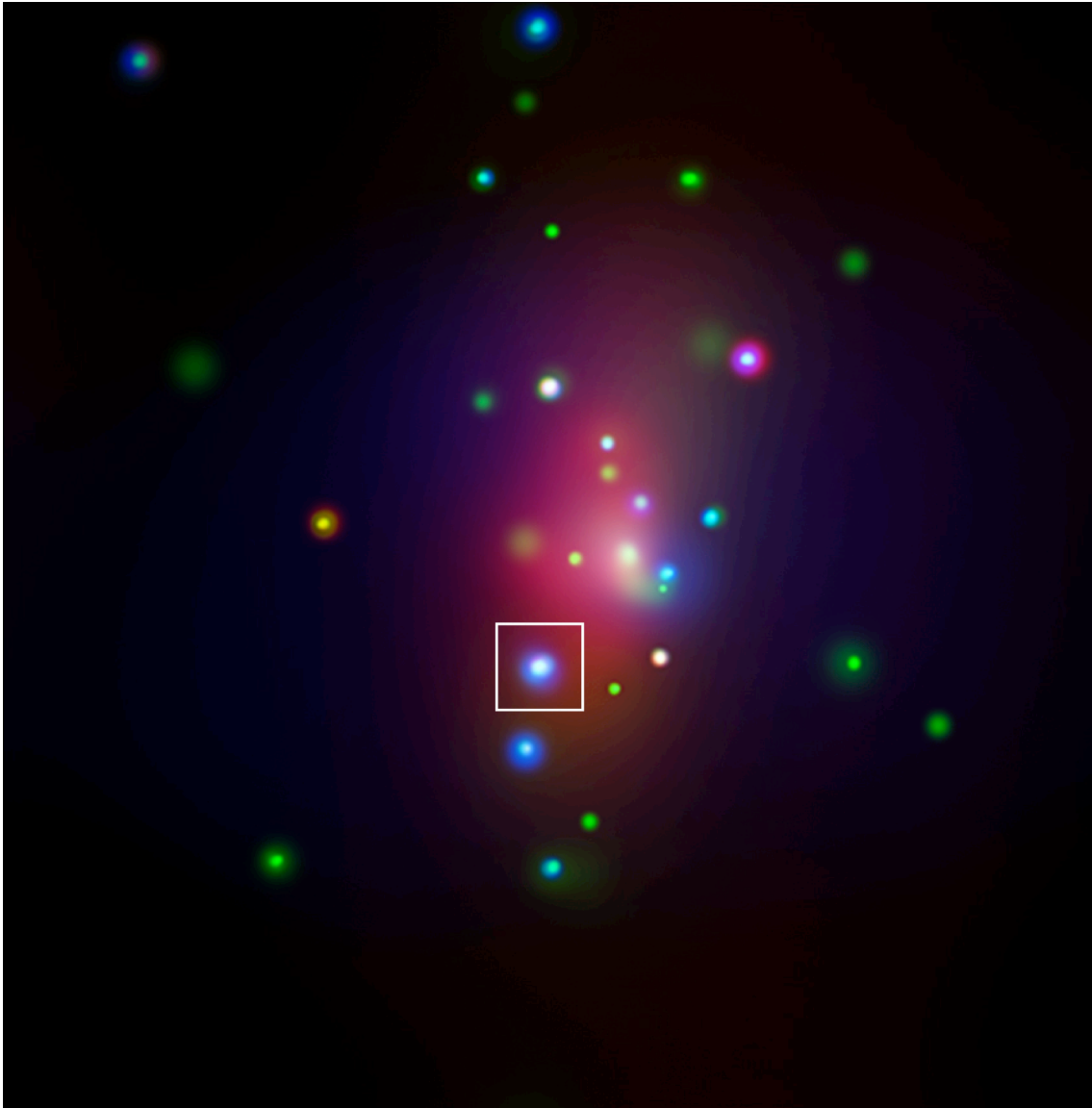
The NASA Astrophysics Advisory Council graded the Division’s progress in this area to be **GREEN**.

**Summary:** (to be prepared by APAC)

The items featured in this section are:

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## NuSTAR Finds New Clues to 'Chameleon Supernova'



This image from NASA's Chandra X-ray Observatory shows spiral galaxy NGC 7331, center, in a three-color X-ray image. Red, green and blue colors are used for low, medium and high-energy X-rays, respectively. An unusual supernova called SN 2014C has been spotted in this galaxy, indicated by the box.

One supernova is challenging astronomers' models of how exploding stars distribute their elements. The supernova SN 2014C, discovered in 2014 in a spiral galaxy about 36 million to 46 million light-years away, dramatically changed in appearance over the course of a year, apparently because it had thrown off a lot of material late in its life. By looking at SN 2014C in optical wavelengths with various ground-based telescopes, astronomers concluded that SN 2014C had transformed itself from a Type I to a Type II supernova after its core collapsed. Initial observations did not detect hydrogen, but, after about a year, it was clear that shock waves propagating from the explosion were hitting a shell of hydrogen-dominated material outside the star.

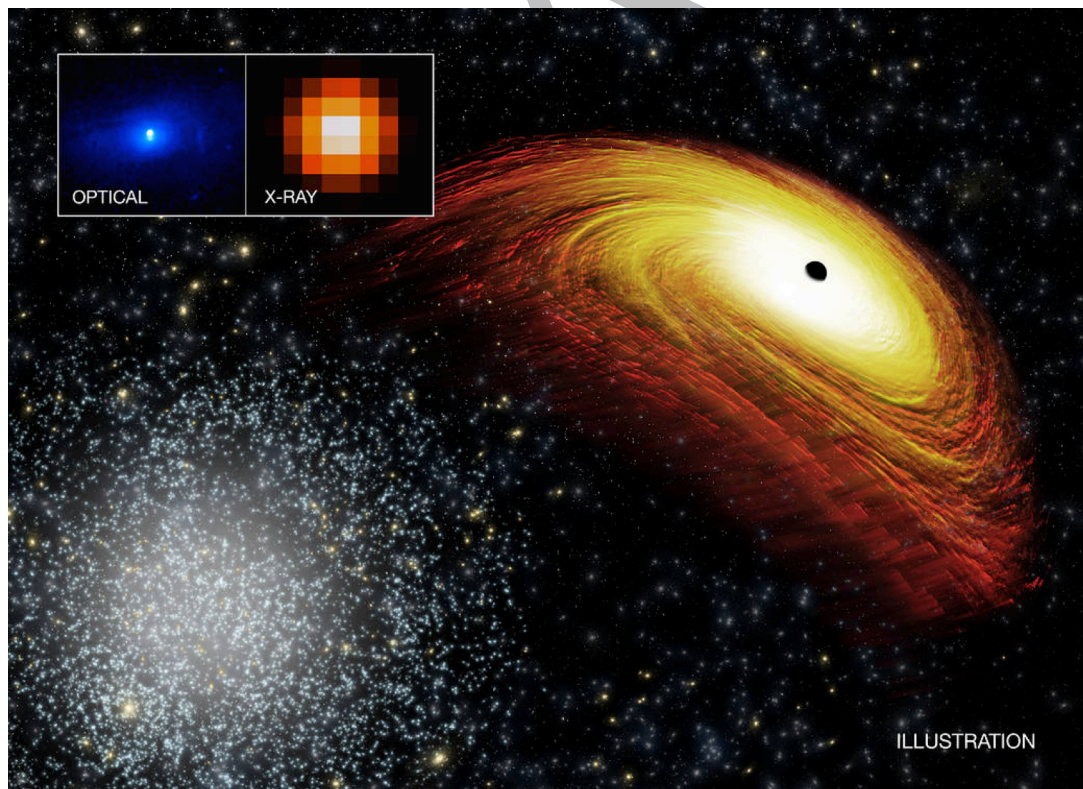
In the new study, NASA's NuSTAR (Nuclear Spectroscopic Telescope Array) satellite allowed scientists to watch how the temperature of electrons accelerated by the supernova shock changed over time. They used this measurement to estimate how fast the supernova expanded and how much material is in the external shell. NASA's Chandra and Swift observatories were also used to further paint the picture of the evolution of the supernova. The collection of observations showed that, surprisingly, the supernova brightened in X-rays after the initial explosion, demonstrating that there must be a shell of material, previously ejected by the star, that the shock waves had hit.

Leading explanations include that there is something missing in our understanding of the nuclear reactions that occur in the cores of massive, supernova-prone stars. Another possibility is that the star did not die alone -- a companion star in a binary system may have influenced the life and unusual death of the progenitor of SN 2014C. This second theory fits with the observation that about seven out of 10 massive stars have companions.

**Margutti, R. et al. 2017, ApJ, 835, 104**

<https://www.nasa.gov/feature/jpl/nustar-finds-new-clues-to-chameleon-supernova>

### **Astronomers Pursue Renegade Supermassive Black Hole**





Supermassive black holes are generally stationary objects, sitting at the centers of most galaxies. However, using data from NASA's Chandra X-ray Observatory and other telescopes, astronomers recently hunted down what could be a supermassive black hole that may be on the move.

This possible renegade black hole, which contains about 160 million times the mass of our Sun, is located in an elliptical galaxy about 3.9 billion light years from Earth. Astronomers are interested in these moving supermassive black holes because they may reveal more about the properties of these enigmatic objects.

This black hole may have "recoiled," in the terminology used by scientists, when two smaller supermassive black holes collided and merged to form an even larger one. At the same time, this collision would have generated gravitational waves that emitted more strongly in one direction than others. This newly formed black hole could have received a kick in the opposite direction of those stronger gravitational waves. This kick would have pushed the black hole out of the galaxy's center, as depicted in the artist's illustration.

The strength of the kick depends on the rate and direction of spin of the two smaller black holes before they merge. Therefore, information about these important but elusive properties can be obtained by studying the speed of recoiling black holes.

Astronomers found this recoiling black hole candidate by sifting through X-ray and optical data for thousands of galaxies. First, they used Chandra observations to select galaxies that contain a bright X-ray source and were observed as part of the Sloan Digital Sky Survey (SDSS). Bright X-ray emission is a common feature of supermassive black holes that are rapidly growing.

Next, the researchers looked to see if Hubble Space Telescope observations of these X-ray bright galaxies revealed two peaks near their center in the optical image. These two peaks might show that a pair of supermassive black holes is present or that a recoiling black hole has moved away from the cluster of stars in the center of the galaxy.

If those criteria were met, then the astronomers examined the SDSS spectra, which show how the amount of optical light varies with wavelength. If the researchers found telltale signatures in the spectra indicative of the presence of a supermassive black hole, they followed up with an even closer examination of those galaxies.

After all of this searching, a good candidate for a recoiling black hole was discovered. The left image in the inset is from the Hubble data, which shows two bright points near the middle of the galaxy. One of them is located at the center of the galaxy and the other is located about 3,000 light years away from the center. The latter source shows the properties of a growing supermassive black hole and its position matches that of a bright X-ray source detected with Chandra (right image in inset). Using data from the SDSS and the Keck telescope in Hawaii, the team determined that the growing black hole located near, but visibly offset from, the center of the galaxy has a velocity that is different from

the galaxy. These properties suggest that this source may be a recoiling supermassive black hole.

**Kim, D.-C., et al. 2017, ApJ, 840, 71**

[https://www.nasa.gov/mission\\_pages/chandra/images/astronomers-pursue-renegade-supermassive-black-hole.html](https://www.nasa.gov/mission_pages/chandra/images/astronomers-pursue-renegade-supermassive-black-hole.html)

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## Astronomers Discover Powerful Cosmic Double Whammy



Composite image using Chandra (red) and the Giant Metreway Radio Telescope (red). Optical data from the Subaru telescope atop Mauna Kea, Hawaii, shows galaxies and stars with a range of different colors.

Using data from NASA's Chandra X-ray Observatory and several other telescopes, astronomers have discovered a cosmic one-two punch unlike any ever seen in a pair of colliding galaxy clusters. This result shows that an eruption from a supermassive black hole combined with a galaxy cluster merger can create a stupendous cosmic particle accelerator.

This cosmic double whammy is found in a pair of colliding galaxy clusters called Abell 3411 and Abell 3412 located about two billion light years from Earth. The two clusters are both very massive, each weighing about a quadrillion — or a million billion — times the mass of the Sun. First, at least one spinning, supermassive black hole in one of the galaxy clusters produced a rotating, tightly-wound magnetic funnel. The powerful electromagnetic fields associated with this structure have accelerated some of the inflowing gas away from the vicinity of the black hole in the form of an energetic, high-speed jet.

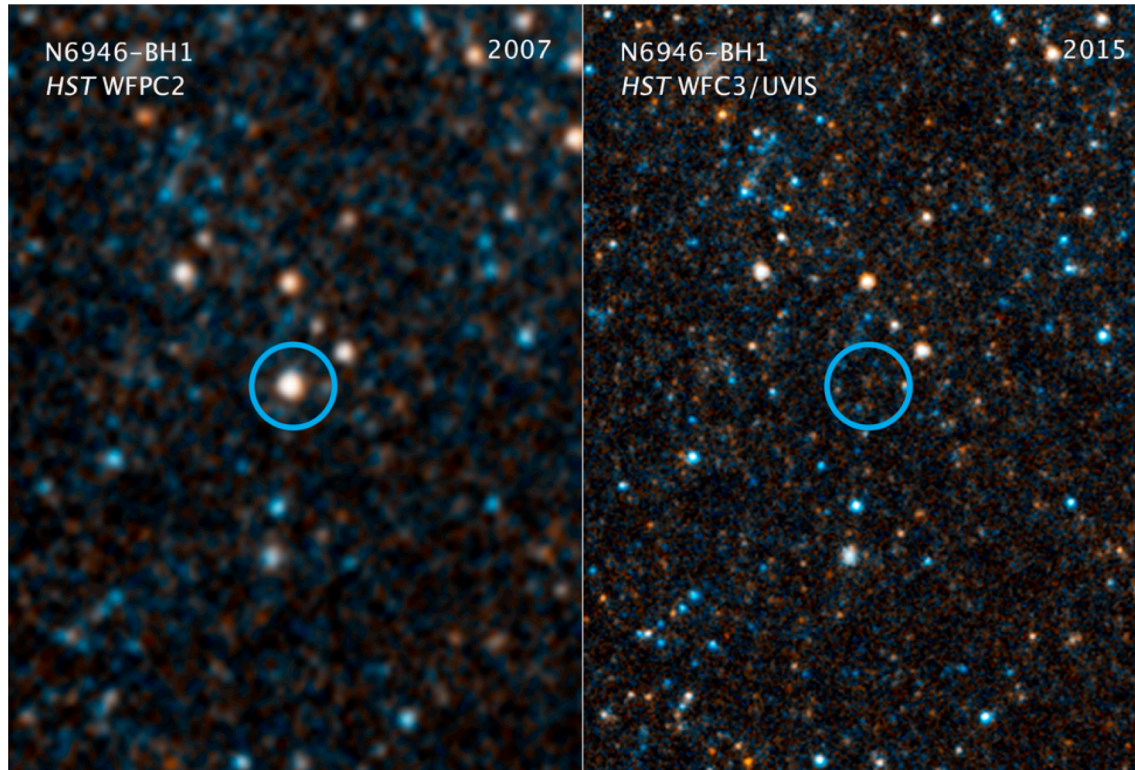
Then, these accelerated particles in the jet were accelerated again when they encountered colossal shock waves — cosmic versions of sonic booms generated by supersonic aircraft — produced by the collision of the massive gas clouds associated with the galaxy clusters.

This result shows that a remarkable combination of powerful events generate these particle acceleration factories, which are the largest and most powerful in the Universe.

Van Weeren, R.J. et al. 2017, *Nature Astronomy*, Volume 1, id. 0005 (2017)

[http://chandra.harvard.edu/press/17\\_releases/press\\_010517.html](http://chandra.harvard.edu/press/17_releases/press_010517.html)

## Collapsing Star Gives Birth to Black Hole



A team of astronomers at The Ohio State University watched a star disappear and possibly become a black hole. Instead of becoming a black hole through the expected process of a supernova, the black hole candidate formed through a "failed supernova."

Astronomers have watched as a massive, dying star was likely reborn as a black hole. It took the combined power of the Large Binocular Telescope (LBT), and NASA's Hubble and Spitzer space telescopes to go looking for remnants of the vanquished star, only to find that it disappeared out of sight.

It went out with a whimper instead of a bang.

The star, which was 25 times as massive as our sun, should have exploded in a very bright supernova. Instead, it fizzled out -- and then left behind a black hole.

"Massive fails" like this one in a nearby galaxy could explain why astronomers rarely see supernovae from the most massive stars, said Christopher Kochanek, professor of astronomy at The Ohio State University and the Ohio Eminent Scholar in Observational Cosmology.

As many as 30 percent of such stars, it seems, may quietly collapse into black holes --no supernova required.

"The typical view is that a star can form a black hole only after it goes supernova," Kochanek explained. "If a star can fall short of a supernova and still make a black hole, that would help to explain why we don't see supernovae from the most massive stars."

He leads a team of astronomers who published their latest results in the Monthly Notices of the Royal Astronomical Society.

Among the galaxies they've been watching is NGC 6946, a spiral galaxy 22 million light-years away that is nicknamed the "Fireworks Galaxy" because supernovae frequently happen there -- indeed, SN 2017eaw, discovered on May 14th, is shining near maximum brightness now. Starting in 2009, one particular star, named N6946-BH1, began to brighten weakly. By 2015, it appeared to have winked out of existence.

After the LBT survey for failed supernovas turned up the star, astronomers aimed the Hubble and Spitzer space telescopes to see if it was still there but merely dimmed. They also used Spitzer to search for any infrared radiation emanating from the spot. That would have been a sign that the star was still present, but perhaps just hidden behind a dust cloud.

All the tests came up negative. The star was no longer there. By a careful process of elimination, the researchers eventually concluded that the star must have become a black hole.

Adams, S., et al. 2017, MNRAS, 468, 4968

<https://www.jpl.nasa.gov/news/news.php?feature=6858>

**Multiyear Performance Goal: 1.6.3:** *Demonstrate progress in exploring the origin and evolution of the galaxies, stars, and planets that make up the Universe.*

**Annual Performance Indicator: FY 2015 AS-15-3:** *Demonstrate planned progress in exploring the origin and evolution of the galaxies, stars, and planets that make up the Universe.*

The NASA Astrophysics Advisory Council graded the Division's progress in this area to be **GREEN**.

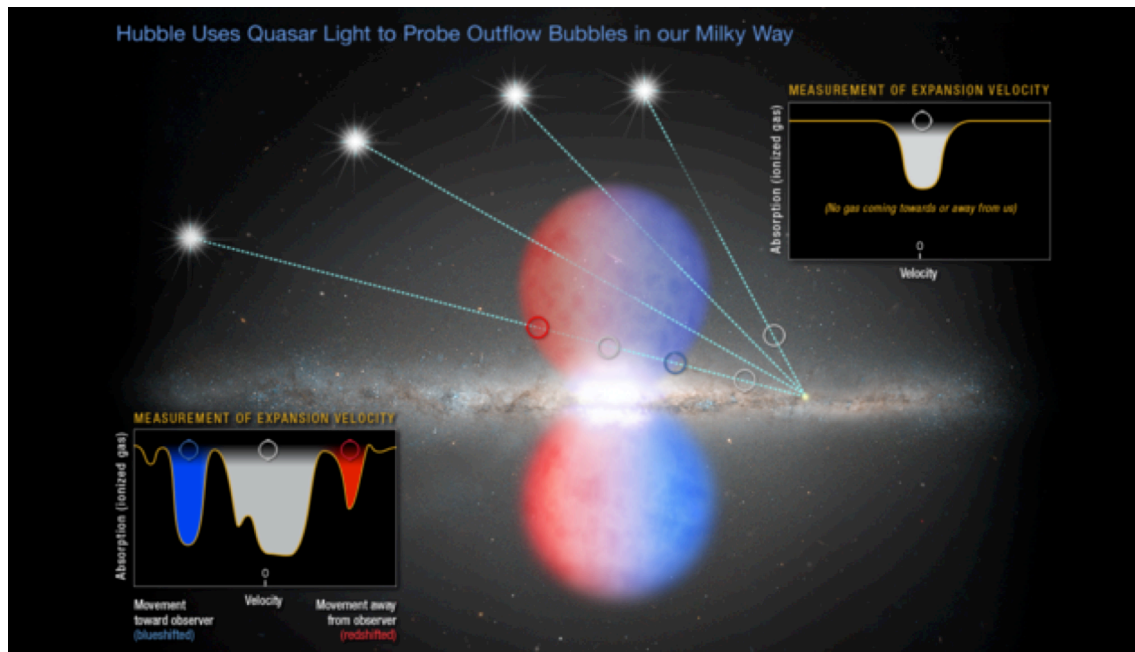
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- Observatories Combine to Crack Open the Crab Nebula
- Hubble Uncovers a Galaxy Pair Coming in from the Wilderness
- "Kitchen Smoke" Molecules in Nebula Offer Clues to the Building Blocks of Life



## Hubble Dates Black Hole's Last Big Meal



This illustration shows the light of several distant quasars piercing the northern half of the Fermi Bubbles, an outflow of gas expelled by our Milky Way galaxy's hefty black hole. The Hubble Space Telescope probed the quasars' light for information on the speed of the gas and whether the gas is moving toward or away from Earth. Based on the material's speed, the research team estimated that the bubbles formed from an energetic event between 6 million and 9 million years ago.

The inset diagram at bottom left shows the measurement of gas moving toward and away from Earth, indicating the material is traveling at a high velocity.

Hubble also observed light from quasars that passed outside the northern bubble. The box at upper right reveals that the gas in one such quasar's light path is not moving toward or away from Earth. This gas is in the disk of the Milky Way and does not share the same characteristics as the material probed inside the bubble.

For the supermassive black hole at the center of our Milky Way galaxy, it's been a long time between dinners. NASA's Hubble Space Telescope has found that the black hole ate its last big meal about 6 million years ago, when it consumed a large clump of infalling gas. After the meal, the engorged black hole burped out a colossal bubble of gas weighing the equivalent of millions of suns, which now billows above and below our galaxy's center.

The immense structures, dubbed the Fermi Bubbles, were first discovered in 2010 by NASA's Fermi Gamma-ray Space Telescope. But recent Hubble observations of the northern bubble have helped astronomers determine a more accurate age for the bubbles and how they came to be. For the first time, HST data allowed astronomers to trace the motion of cool gas throughout one of the bubbles, mapping the velocity of the gas, and calculate when the bubbles formed. They found that a very strong, energetic event happened 6 million to 9 million years ago. It may have been a cloud of gas flowing into the black hole, which fired off jets of matter, forming the twin lobes of hot gas seen in X-ray and gamma-ray observations.

A black hole is a dense, compact region of space with a gravitational field so intense that neither matter nor light can escape. The supermassive black hole at the center of our galaxy has compressed the mass of 4.5 million sun-like stars into a very small region of space. Material that gets too close to a black hole is caught in its powerful gravity and swirls around the compact powerhouse until it eventually falls in. Some of the matter, however, gets so hot it escapes along the black hole's spin axis, creating an outflow that extends far above and below the plane of a galaxy.

The HST observations measured the temperature of the gas in the bubble at approximately 17,700 degrees Fahrenheit. Even at those sizzling temperatures, this gas is much cooler than most of the super-hot gas in the outflow, which is 18 million degrees Fahrenheit, seen in gamma rays. The cooler gas seen by HST could be interstellar gas from our galaxy's disk that is being swept up and entrained into the super-hot outflow. HST also identified silicon and carbon as two of the elements being swept up in the gaseous cloud. These common elements are found in most galaxies and represent the fossil remnants of stellar evolution.

The cool gas is racing through the bubble at 2 million miles per hour. By mapping the motion of the gas throughout the structure, the astronomers estimated that the minimum mass of the entrained cool gas in both bubbles is equivalent to 2 million suns. The edge of the northern bubble extends 23,000 light-years above the galaxy.

**Bordoloi, R. et al. 2017, ApJ, 834, 191**

[http://hubblesite.org/news\\_release/news/2017-10](http://hubblesite.org/news_release/news/2017-10)

## Observatories Combine to Crack Open the Crab Nebula



This composite image of the Crab Nebula, a supernova remnant, was assembled by combining data from five telescopes spanning nearly the entire breadth of the electromagnetic spectrum: the Very Large Array, the Spitzer Space Telescope, the Hubble Space Telescope, the XMM-Newton Observatory, and the Chandra X-ray Observatory.

Using data from NASA's Chandra, Hubble, and Spitzer, combined with ground-based radio observations, astronomers have produced a highly-detailed image of the Crab Nebula.

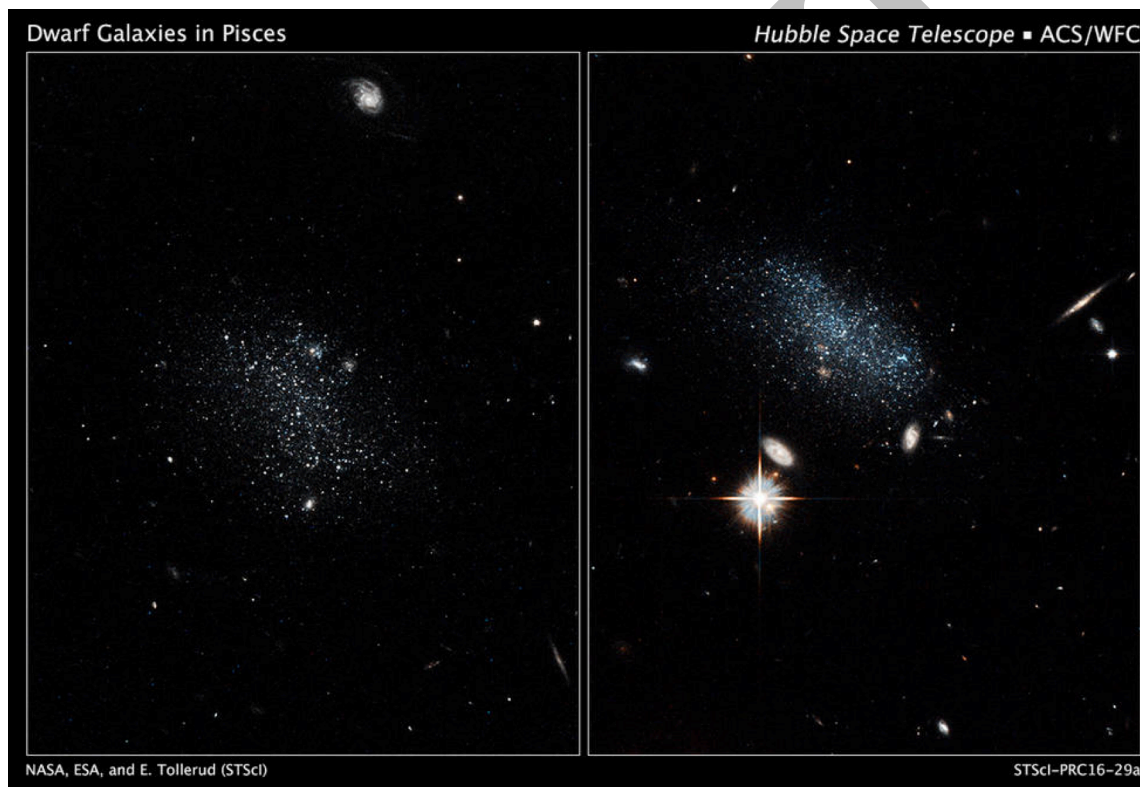
The Crab Nebula, the result of a bright supernova explosion seen by Chinese and other astronomers in the year 1054, is 6,500 light-years from Earth. At its center is a super-

dense neutron star, rotating once every 33 milliseconds, shooting out rotating lighthouse-like beams of radio waves and light -- a pulsar (the bright dot at image center). The nebula's intricate shape is caused by a complex interplay of the pulsar, a fast-moving wind of particles coming from the pulsar, and material originally ejected by the supernova explosion and by the star itself before the explosion.

**Dubner, G. et al. 2017, ApJ, 840, 82**

<https://www.nasa.gov/feature/goddard/2017/observatories-combine-to-crack-open-the-crab-nebula>

## Hubble Uncovers a Galaxy Pair Coming in from the Wilderness



NASA's Hubble Space Telescope has captured the glow of new stars in these small, ancient galaxies, called Pisces A and Pisces B. The dwarf galaxies have lived in isolation for billions of years and are just now beginning to make stars.

NASA's Hubble Space Telescope has uncovered two tiny dwarf galaxies that have wandered from a vast cosmic wilderness into a nearby "big city" packed with galaxies.

The Hubble observations suggest that the galaxies, called Pisces A and B, are late bloomers because they have spent most of their existence in the Local Void, a region of the universe sparsely populated with galaxies. The Local Void is roughly 150 million light-years across.

Under the steady pull of gravity from the other galaxies, the dwarf galaxies have entered a crowded region that is denser in intergalactic gas. In this gas-rich environment, star birth may have been triggered by gas raining down on the galaxies as they plow through the denser region. Another idea is that the duo may have encountered a gaseous filament, which compresses gas in the galaxies and stokes star birth. Dwarf galaxies are the building blocks from which larger galaxies were formed billions of years ago in the early universe. Inhabiting a sparse desert of largely empty space for most of the universe's history, these two galaxies avoided that busy construction period. These galaxies may have spent most of their history in the void. If this is true, the void environment would have slowed their evolution.

**Tollerud, E.J. et al. 2016, ApJ, 827, 89**

<https://www.nasa.gov/feature/goddard/2016/hubble-uncovers-a-galaxy-pair-coming-in-from-the-wilderness>



## **“Kitchen Smoke” Molecules in Nebula Offer Clues to the Buildin Blocks of Life**



Combination of three color images of NGC 7023 from SOFIA (red & green) and Spitzer (blue) show different populations of PAH molecules.

Using data collected by NASA’s Stratospheric Observatory for Infrared Astronomy (SOFIA) and other observatories, an international team of researchers has studied how a particular type of organic molecules, the raw materials for life – could develop in space.

This information could help scientists better understand how life could have developed on Earth.

Bavo Croiset of Leiden University in the Netherlands and his collaborators focused on a type of molecule called polycyclic aromatic hydrocarbons (PAHs), which are flat molecules consisting of carbon atoms arranged in a honeycomb pattern, surrounded by hydrogen. PAHs make up about 10 percent of the carbon in the universe, and are found on the Earth where they are released upon the burning of organic material such as meat, sugarcane, wood etc. Croiset's team determined that when PAHs in the nebula NGC 7023, also known as the Iris Nebula, are hit by ultraviolet radiation from the nebula's central star, they evolve into larger, more complex molecules. Scientists hypothesize that the growth of complex organic molecules like PAHs is one of the steps leading to the emergence of life.

Some existing models predicted that the radiation from a newborn, nearby massive star would tend to break down large organic molecules into smaller ones, rather than build them up. To test these models, researchers wanted to estimate the size of the molecules at various locations relative to the central star.

**Croiset, B., et al. 2016, A&A, 590, 26**

<https://www.nasa.gov/feature/kitchen-smoke-molecules-in-nebula-offer-clues-to-the-building-blocks-of-life>

**Multiyear Performance Goal: 1.6.4:** *Demonstrate progress in discovering and studying planets around other stars and exploring whether they could harbor life*

**Annual Performance Indicator: FY 2015 AS-15-6:** *Demonstrate planned progress in discovering and studying planets around other stars and exploring whether they could harbor life*

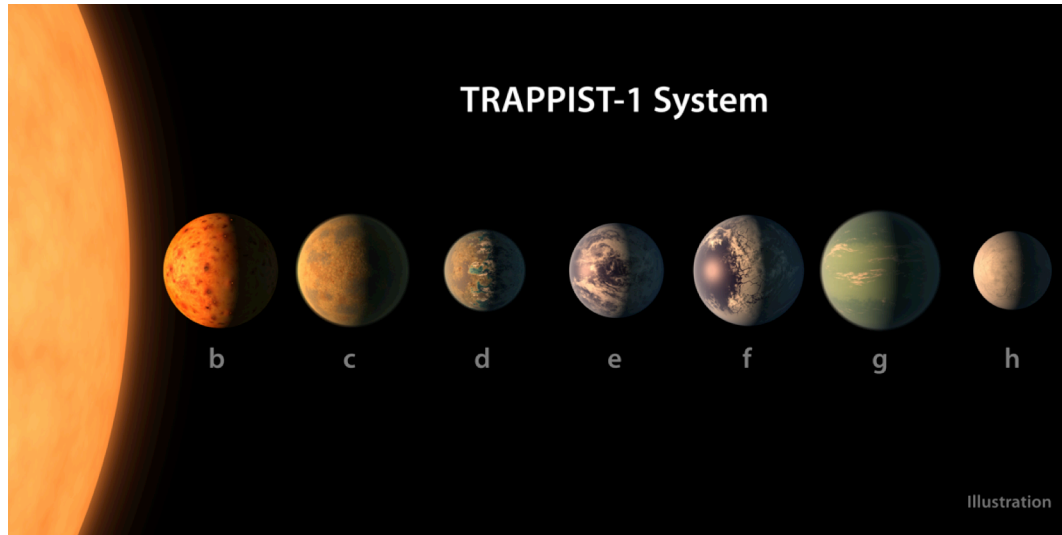
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- NASA Telescope Reveals Largest Batch of Earth-Size, Habitable-Zone Planets Around Single Star
- NASA Releases Kepler Survey Catalog with Hundreds of New Planet Candidates
- Small Planets Come in Two Sizes
- NASA Study Finds Unexpectedly Primitive Atmosphere Around 'Warm Neptune'

## NASA Telescope Reveals Largest Batch of Earth-Size, Habitable-Zone Planets Around Single Star



This artist's concept shows what each of the TRAPPIST-1 planets may look like, based on available data about their sizes, masses and orbital distances.

NASA's Spitzer Space Telescope has revealed the first known system of seven Earth-size planets around a single star. Three of these planets are firmly located in the habitable zone, the area around the parent star where a rocky planet is most likely to have liquid water.

The discovery sets a new record for greatest number of habitable-zone planets found around a single star outside our solar system. All of these seven planets could have liquid water – key to life as we know it – under the right atmospheric conditions, but the chances are highest with the three in the habitable zone.

“This discovery could be a significant piece in the puzzle of finding habitable environments, places that are conducive to life,” said Thomas Zurbuchen, associate administrator of the agency’s Science Mission Directorate in Washington. “Answering the question ‘are we alone’ is a top science priority and finding so many planets like these for the first time in the habitable zone is a remarkable step forward toward that goal.” At about 40 light-years (235 trillion miles) from Earth, the system of planets is relatively close to us, in the constellation Aquarius. Because they are located outside of our solar system, these planets are scientifically known as exoplanets.

This exoplanet system is called TRAPPIST-1, named for The Transiting Planets and Planetesimals Small Telescope (TRAPPIST) in Chile. In May 2016, researchers using

TRAPPIST announced they had discovered three planets in the system. Assisted by several ground-based telescopes, including the European Southern Observatory's Very Large Telescope, Spitzer confirmed the existence of two of these planets and discovered five additional ones, increasing the number of known planets in the system to seven. The new results were published Wednesday in the journal *Nature*, and announced at a news briefing at NASA Headquarters in Washington.

Using Spitzer data, the team precisely measured the sizes of the seven planets and developed first estimates of the masses of six of them, allowing their density to be estimated.

Based on their densities, all of the TRAPPIST-1 planets are likely to be rocky. Further observations will not only help determine whether they are rich in water, but also possibly reveal whether any could have liquid water on their surfaces. The mass of the seventh and farthest exoplanet has not yet been estimated – scientists believe it could be an icy, "snowball-like" world, but further observations are needed.

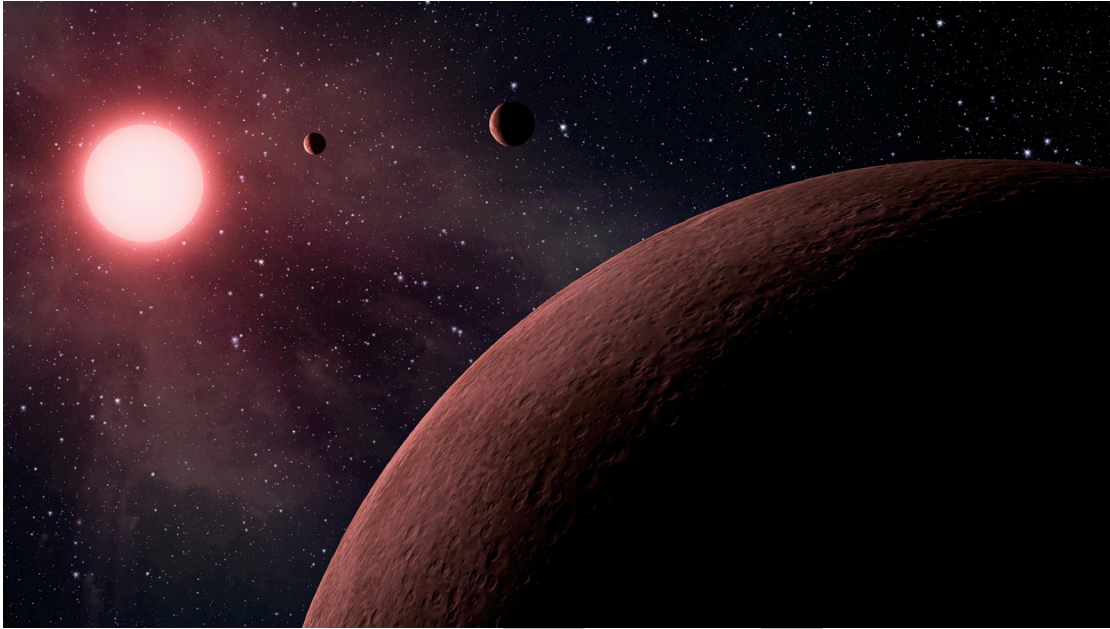
"The seven wonders of TRAPPIST-1 are the first Earth-size planets that have been found orbiting this kind of star," said Michael Gillon, lead author of the paper and the principal investigator of the TRAPPIST exoplanet survey at the University of Liege, Belgium. "It is also the best target yet for studying the atmospheres of potentially habitable, Earth-size worlds."

In contrast to our sun, the TRAPPIST-1 star – classified as an ultra-cool dwarf – is so cool that liquid water could survive on planets orbiting very close to it, closer than is possible on planets in our solar system. All seven of the TRAPPIST-1 planetary orbits are closer to their host star than Mercury is to our sun. The planets also are very close to each other. If a person was standing on one of the planet's surface, they could gaze up and potentially see geological features or clouds of neighboring worlds, which would sometimes appear larger than the moon in Earth's sky.

<http://www.spitzer.caltech.edu/news/1924-ssc2017-01>

**Gillon, M. et al. 2017, *Nature*, 542, 456**

## NASA Releases Kepler Survey Catalog with Hundreds of New Planet Candidates



NASA's Kepler space telescope team has identified 219 new planet candidates, 10 of which are near-Earth size and in the habitable zone of their star.

NASA's Kepler space telescope team has released a mission catalog of planet candidates that introduces 219 new candidates, 10 of which are near-Earth size and orbiting in their star's habitable zone, which is the range of distance from a star where liquid water could pool on the surface of a rocky planet.

This is the most comprehensive and detailed catalog release of candidate exoplanets, which are planets outside our solar system, from Kepler's first four years of data. It's also the final catalog from the spacecraft's view of the patch of sky in the Cygnus constellation.

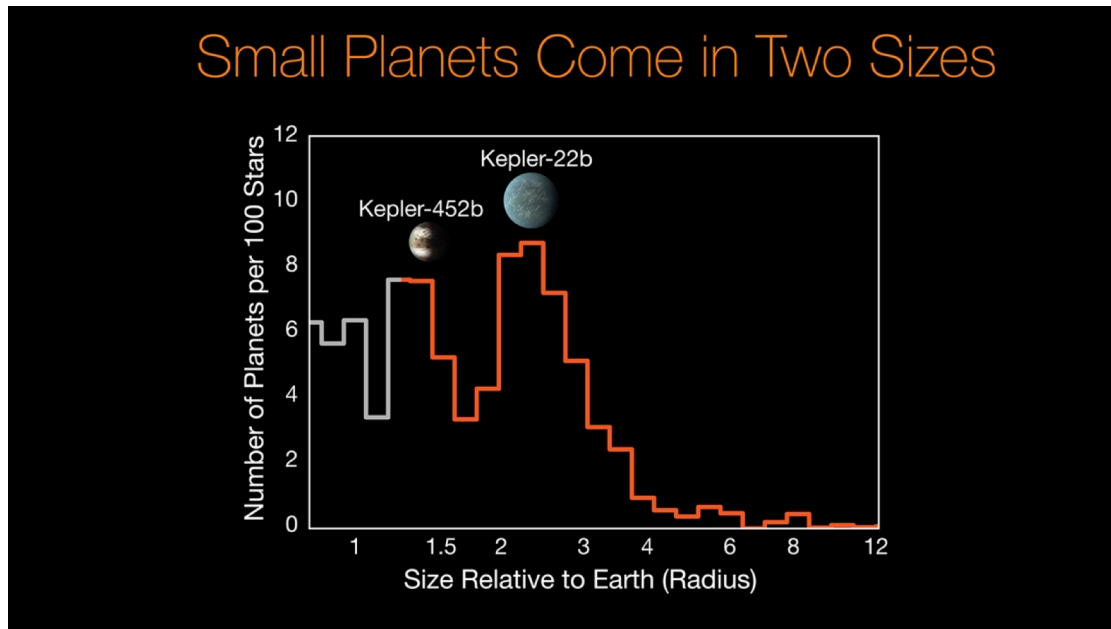
With the release of this catalog, derived from data publicly available on the NASA Exoplanet Archive, there are now 4,034 planet candidates identified by Kepler. Of those, 2,335 have been verified as exoplanets. Of roughly 50 near-Earth size habitable zone candidates detected by Kepler, more than 30 have been verified.

**Twicken, et al. 2016, AJ, 152, 158**

<https://exoplanets.nasa.gov/news/1443/nasa-releases-kepler-survey-catalog-with-hundreds-of-new-planet-candidates/>



## Small Planets Come in Two Sizes



Researchers using data from the W. M. Keck Observatory and NASA's Kepler mission have discovered a gap in the distribution of planet sizes, indicating that most planets discovered by Kepler so far fall into two distinct size classes: the rocky Earths and super-Earths (similar to Kepler-452b), and the mini-Neptunes (similar to Kepler-22b). This histogram shows the number of planets per 100 stars as a function of planet size relative to Earth. Credit: Image credit: NASA/Ames/Caltech/University of Hawaii (B. J. Fulton)

Using Kepler data, researchers have found two distinct size groupings of small planets. This result could have significant implications for the search for life. The discovery of the two distinct planetary populations shows that about half the planets we know of in the galaxy either have no surface, or lie beneath a deep, crushing atmosphere— an environment unlikely to host life.

The research group took advantage of the Kepler data to make precise measurements of thousands of planets, revealing two distinct groups of small planets. The team found a clean division in the sizes of rocky, Earth-size planets and gaseous planets smaller than Neptune. Few planets were found between those groupings.

Using the W. M. Keck Observatory in Hawaii, the group measured the sizes of 1,300 stars in the Kepler field of view to determine the radii of 2,000 Kepler planets with exquisite precision.

“We like to think of this study as classifying planets in the same way that biologists identify new species of animals,” said Benjamin Fulton, doctoral candidate at the University of Hawaii in Manoa, and lead author of the second study. “Finding two

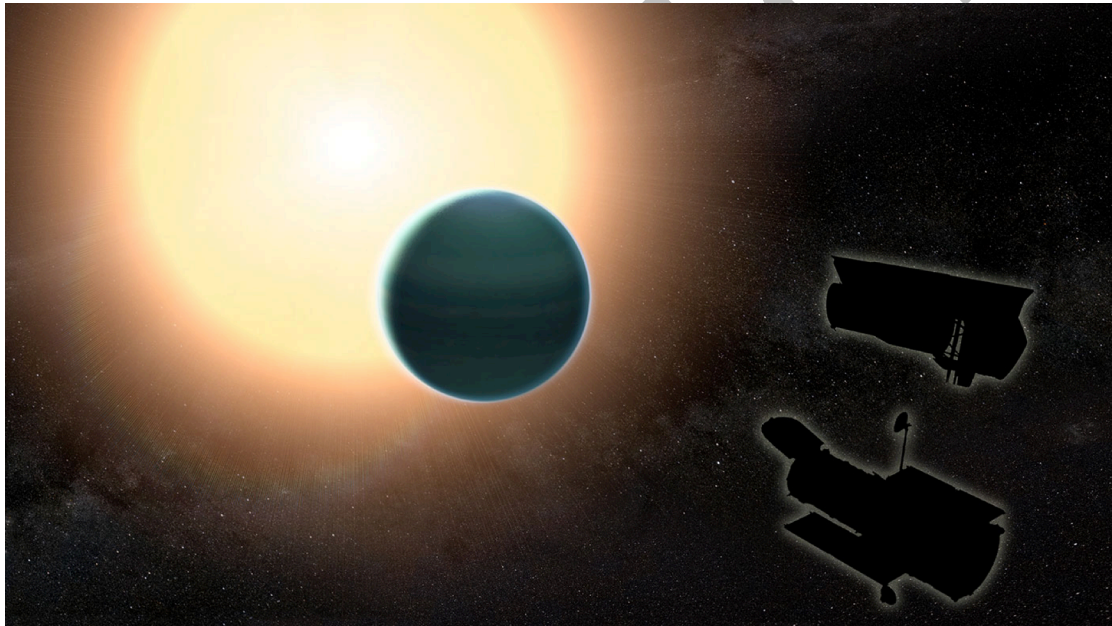
distinct groups of exoplanets is like discovering mammals and lizards make up distinct branches of a family tree.”

It seems that nature commonly makes rocky planets up to about 75 percent bigger than Earth. For reasons scientists don't yet understand, about half of those planets take on a small amount of hydrogen and helium that dramatically swells their size, allowing them to "jump the gap" and join the population closer to Neptune's size.

**Fulton et al., 2017, AJ, in press**

<https://exoplanets.nasa.gov/news/1443/nasa-releases-kepler-survey-catalog-with-hundreds-of-new-planet-candidates/>

## **NASA Study Finds Unexpectedly Primitive Atmosphere Around ‘Warm Neptune’**



The atmosphere of the distant "warm Neptune" HAT-P-26b, illustrated here, is unexpectedly primitive, composed primarily of hydrogen and helium.

A study combining observations from NASA's Hubble and Spitzer space telescopes reveals that the distant planet HAT-P-26b has a primitive atmosphere composed almost entirely of hydrogen and helium. Located about 437 light years away, HAT-P-26b orbits a star roughly twice as old as the sun.

The analysis is one of the most detailed studies to date of a "warm Neptune," or a planet that is Neptune-sized and close to its star. The researchers determined that HAT-P-26b's atmosphere is relatively clear of clouds and has a strong water signature, although the

planet is not a water world. This is the best measurement of water to date on an exoplanet of this size.

The discovery of an atmosphere with this composition on this exoplanet has implications for how scientists think about the birth and development of planetary systems. Compared to Neptune and Uranus, the planets in our solar system with about the same mass, HAT-P-26b likely formed either closer to its host star or later in the development of its planetary system, or both.

To study HAT-P-26b's atmosphere, the researchers used data from transits— occasions when the planet passed in front of its host star. During a transit, a fraction of the starlight gets filtered through the planet's atmosphere, which absorbs some wavelengths of light but not others. By looking at how the signatures of the starlight change as a result of this filtering, researchers can work backward to figure out the chemical composition of the atmosphere.

In this case, the team pooled data from four transits measured by Hubble and two seen by Spitzer. Together, those observations covered a wide range of wavelengths from yellow light through the near-infrared region.

Because the study provided a precise measurement of water, the researchers were able to use the water signature to estimate HAT-P-26b's metallicity. Astronomers calculate the metallicity, an indication of how rich the planet is in all elements heavier than hydrogen and helium, because it gives them clues about how a planet formed.

To compare planets by their metallicities, scientists use the sun as a point of reference, almost like describing how much caffeine beverages have by comparing them to a cup of coffee. Jupiter has a metallicity about 2 to 5 times that of the sun. For Saturn, it's about 10 times as much as the sun. These relatively low values mean that the two gas giants are made almost entirely of hydrogen and helium.

The ice giants Neptune and Uranus are smaller than the gas giants but richer in the heavier elements, with metallicities of about 100 times that of the sun. So, for the four outer planets in our solar system, the trend is that the metallicities are lower for the bigger planets.

Scientists think this happened because, as the solar system was taking shape, Neptune and Uranus formed in a region toward the outskirts of the enormous disk of dust, gas and debris that swirled around the immature sun. Summing up the complicated process of planetary formation in a nutshell: Neptune and Uranus would have been bombarded with a lot of icy debris that was rich in heavier elements. Jupiter and Saturn, which formed in a warmer part of the disk, would have encountered less of the icy debris.

**Wakeford, H. R. et al. 2017, *Science*, 356, 628**

<https://www.nasa.gov/feature/goddard/2017/nasa-study-finds-unexpectedly-primitive-atmosphere-around-warm-neptune>

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